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Coronal plane ankle alignment, gait, and end-stage ankle osteoarthritis

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SUMMARY

Objective: Unilateral ankle osteoarthritis (OA) is a debilitating condition which may lead to limb deformity, severe pain, and functional disability due to tibiotalar malalignment and gait dysfunction. The purpose of this study was to determine if coronal plane alignment (varus, valgus, or neutral) of the ankle resulted in different spatial-temporal gait mechanics, clinically-assessed function, and self-reported function in patients with end-stage ankle OA.
Methods: Following informed consent, 96 patients with end-stage unilateral ankle OA were radiographically categorized as having varus, valgus, or neutral tibiotalar alignment. Each subject completed the foot and ankle disability index (FADI) questionnaire to assess self-reported function. The spatial-temporal parameters of interest (stance time, step length, stride length, stride width, single-support time, double support time, and walking speed) were assessed while the subject walked at a self-selected speed.
Results: The varus group performed the timed up and go test significantly faster than the other groups ($P = 0.05$). All other variables were similar between the three alignment groups.
Conclusion: There was little difference in gait mechanics and function between patients with end-stage OA based on coronal plane ankle alignment suggesting that factors other than coronal plane alignment contribute to diminished function.

Introduction

Unilateral ankle osteoarthritis (OA) is a debilitating condition which may lead to deformity, severe pain, and functional disability[1]. Unlike other major joint arthroses, ankle OA tends to be post-traumatic, which often affects younger populations with longer projected lifespans[2]. Important secondary causes of ankle arthritis include traumatic injury, sepsis, rheumatoid arthritis, osteonecrosis, neuropathic arthritis and gout[3]. Each of these conditions can cause or exacerbate underlying tibiotalar malalignment in this population. While ankle OA is less prevalent than knee or hip OA, the degree of physical impairment associated with ankle OA is similar to that reported in patients with end-stage kidney disease[4], congestive heart failure[4], and end-stage hip arthritis[5].

The principal goals of any ankle reconstruction surgery will be to recreate (1) a quasi-anatomical reconstruction of the natural geometry, (2) a stable and plantigrade foot position to restore acceptable gait function, and (3) the return of more normal soft tissue function around the ankle[6]. The two options for surgical treatment of end-stage ankle OA are either total ankle arthroplasty or ankle arthrodesis. Currently, the choice between these two surgical options is controversial, particularly as it pertains to addressing the aforementioned surgical goals. Based on the currently available literature, total ankle replacement continues to be performed less frequently than ankle arthrodesis because studies that examine gait and self-reported function following total ankle replacement are limited and longevity of the prosthesis has been short[7–9]. For these reasons, further data are needed on the clinical, functional, and gait mechanics outcomes of total ankle replacement as an effective treatment for ankle OA. In order to demonstrate the effectiveness of a surgical procedure at restoring gait and function, pre-operative gait and functional data is helpful for both group and longitudinal comparisons.

Previous studies on coronal plane ankle alignment and OA highlight a clear association between the two. Valderrbano *et al.*[10] discussed the etiologies of ankle OA and found no difference in hindfoot malalignment distribution among etiologic groups, but did find that the average tibiotalar alignment was varus in their patient population. Interestingly, Harrington[11] reported that

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chronic ligamentous instability, which can lead to degenerative ankle arthritis, was more likely to be associated with a varus deformity. Horisberger *et al.*[12] tied hindfoot malalignment in arthritic ankles to alterations in plantar pressure distribution with the varus alignment being the most prevalent in their patient population. Still, valgus deformities do occur in patients with ankle OA. Pagenstert *et al.*[13] hypothesized that valgus deformities were better compensated by the subtalar joint during end-stage OA because the natural range of ankle eversion motion exceeds the range on inversion motion. Ultimately, changes in ankle alignment in the sagittal plane, as shown by Kura *et al.*[14], alter the contact frequency within the ankle joint, either lateralizing contact with eversion or medializing contact with inversion.

The goal of this study was to determine if coronal plane alignment of the tibiotalar joint (varus, valgus, or neutral) resulted in significantly different spatial-temporal gait variables, clinically-assessed function, and self-reported function in patients with end-stage ankle OA. The current study is an important preliminary step in addressing whether coronal plane alignment influences spatial-temporal variables during walking. Should alignment affect gait, the data may help to identify prospectively which patients will respond more favorably to total ankle arthroplasty.

Methods

Patient recruitment

For this prospective, non-randomized study, 100 consecutive patients from a larger clinical series of patients with end-stage ankle OA, who were scheduled for total ankle arthroplasty between 2007 and 2009, were recruited. Prior to data collection, all study participants signed an informed consent that had been approved by the medical center institutional review board. Patients were excluded from this study if they were unable to walk without the use of an assistive device, if they had bilateral ankle OA and/or a history of previous ankle arthrodesis. Out of the original 100 patients who were consented to participate in the study, 96 were included in the final analysis as four failed to meet the inclusion/exclusion criteria for the study. Out of the 96 patients tested 13 had a prior total knee arthroplasty (TKA) and 12 had a prior total hip arthroplasty (THA).

Clinical and radiographic assessment

Using standard weight bearing radiographs each patient was categorized as having varus, valgus or neutral tibiotalar alignment according to the method of Kim *et al.*[15] Patients were divided into groups based on their tibiotalar alignment as follows: (1) Valgus: greater than 5° of valgus, (2) Neutral: between 4° of varus − 4° of valgus, (3) Varus: greater than 5° of varus. The anteroposterior tibiotalar angle was defined as the angle between the long axis of the tibia and a line perpendicular to the articular surface of the dome of the talus on the weight bearing anteroposterior radiographic view (Fig. 1)[15]. The categorization process of the 96 subjects in the study resulted in 27 valgus, 34 neutral, and 35 varus patients. Following informed consent, each subject completed the foot and ankle disability index (FADI) questionnaire to assess self-reported function. The FADI (recently revised and now called the Foot and Ankle Ability Measure) consists of 26 questions about activities of daily living and has been previously reported in an ankle arthritis population[16].

In addition, each subject completed a series of clinically relevant functional tasks. The patients completed a timed up and go test (TUG) that consisted of rising from a standard arm chair, walking 3 m and then returning to the standard arm chair as quickly as possible. The TUG has high reliability and correlates well with other standard functional measures such as gait speed, self-report, and clinical report indices of function and is predictive of who can safely ambulate[17]. In addition, the TUG has been previously reported to be one of four factors that is important to assess in patients with end-stage ankle OA[18].

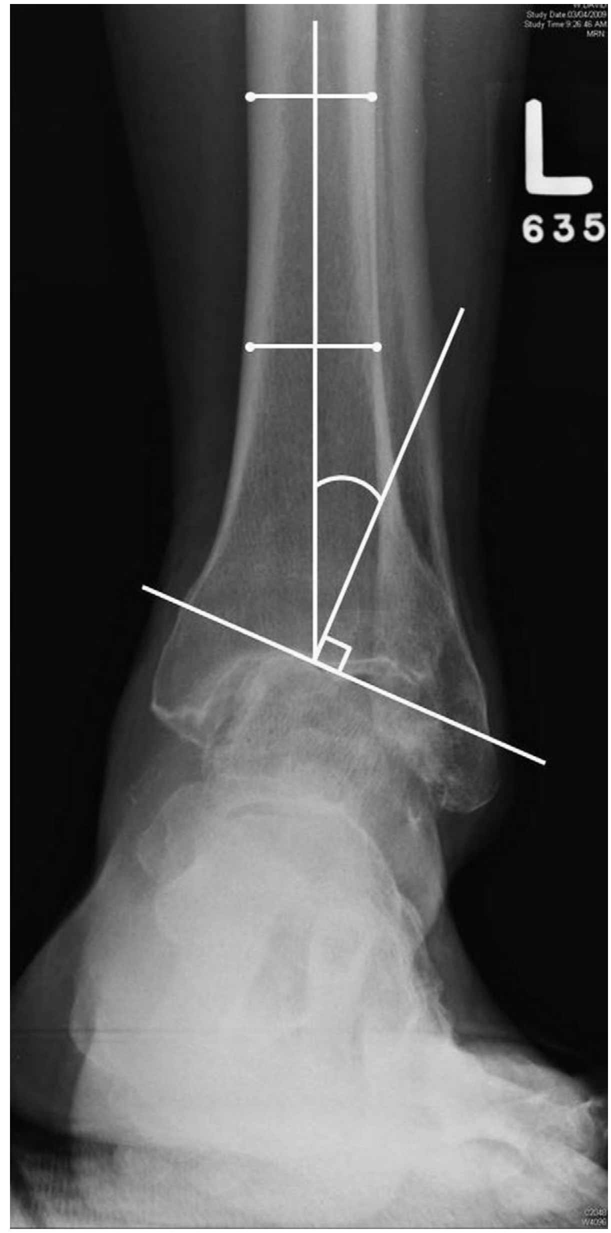

Fig. 1. Example of the radiographic assessment to determine the coronal plane alignment.

Walking assessment

Each patient was asked to complete a walking assessment during his or her visit. Spatial-temporal gait data were assessed using an eight-camera three-dimensional videographic motion analysis system sampling at 120 Hz (Motion Analysis Corporation; Santa Rosa, California) and four force plates (AMTI, Watertown, Massachusetts). Each subject completed seven barefoot walking trials at a self-selected walking speed along a 30-m walkway. Data were collected bilaterally, however, only the limb with end-stage OA was

Table I
Means and standard deviations of patient demographics by tibiotalar alignment

Variable	Valgus	Neutral	Varus	$P=$
Age (years)	66.30 ± 11.91	63.18 ± 10.93	62.77 ± 7.01	0.342
Stature (m)	1.69 ± 0.09	1.68 ± 0.09	1.71 ± 0.14	0.480
Mass (kg)	81.18 ± 16.68	79.479 ± 14.18	91.47 ± 18.373	0.007*

* Varus > neutral, valgus.

used for statistical analysis. The spatial-temporal parameters of interest were stance time, step length, stride length, stride width, single-support time, double support time, and walking speed.

Step length was defined as the distance between the heel of one foot and the heel of the contralateral foot during the double support phase of gait. Stride length is the distance between the heel strike of one foot and the next heel strike of the same foot. Both step length and stride length were normalized to the subject's standing height. The temporal parameters obtained were stance time, step time, and swing time. Stance time is the time from heel strike on one foot to toe-off of the same foot. Step time is the time from heel strike of one foot to the heel strike by the contralateral foot. Finally, swing time is from toe-off of one foot to heel strike of the same foot. Each of these variables was normalized as a percentage of the gait cycle. Single-support and double support time was calculated as a percentage of the stance phase of gait. In addition, gait speed was determined as the average linear velocity of the sacral marker (marker placed at the joint between the fifth lumbar vertebrae and the sacrum) during the seven walking trials. The sacral marker location has been used previously as an estimation of the center of mass of the body and, therefore, is the marker location for determining gait speed[19]. Gait speed is a global measure of disability and function and has been correlated with disease processes, fitness level, activities of daily living, and emotional states[20]. Gait speed has been previously used in this population as a measure of the differences in functional ability[18].

Statistical analysis

Routine descriptive statistics were used to summarize the data. In addition, a series of one factor ANOVAs examined for differences between the three coronal plane tibiotalar alignment groups ($P < 0.05$). Significant F ratios were followed up using Tukey's *post-hoc* procedure. All statistical analyses were performed using SPSS (Chicago, IL).

Results

This study included 96 subjects who were radiographically categorized as having valgus, varus, or neutral tibiotalar alignment. There were no significant group differences in age or height, but body mass differed with the patients in the varus group being significantly heavier than patients in the neutral ($P = 0.003$) and the valgus ($P = 0.017$) patients (Table I). Of the 96 patients, 56 were male and 40 were female. Of the 96 patients tested, 13 had a prior TKA and 12 had a prior THA. The numbers in each of the alignment groups were similar with five TKA and six THA in the valgus group, four TKA and three THA in the neutral group and four TKA and two THA in the varus group.

The timed up and go (TUG) measurement was the only functional variable that was statistically significantly different between the three groups ($P = 0.05$) (Table II). *Post-hoc* analysis showed that patients in the neutral group (9.9 ± 3.7 s; mean, S.D.) were significantly slower than patients in the varus group (8.1 ± 1.7 s). No other group differences were observed.

The remaining variables of interest included the mean FADI score, mean walking speed as well as mean stance time on the affected side, step length of the affected side, stride length of the affected side, mean stride width and percent of the gait cycle spent in single support on the affected side (Table II). There were no significant differences in the FADI score between the three groups. In addition, there were no group differences for walking speed, or stance time on the affected side, step length of the affected side, stride length of the affected side, percent of gait cycle spent in single support on the affected side, or stride width.

Discussion

We analyzed pre-operative spatial-temporal gait variables plus clinically-assessed and self-reported function of 96 patients with end-stage ankle OA grouped by coronal plane tibiotalar alignment. The only significant difference was in the functional TUG test with the patients with varus alignment performing the task faster (8.1 s) than the patients with neutral alignment (9.9 s). The FADI score, walking speed, stance time, step length, stride length, stride width, nor single-support time differed based on coronal plane tibiotalar alignment. Surprisingly, these subgroups differed very little from each other on gait or function. While weight was significantly different between the groups, the variables of interest for this study would not be significantly influenced by differences in weight.

In patients with ankle OA, coronal tibiotalar alignment may be an easily categorized parameter, but gait analysis is an objective and quantifiable tool that is sensitive to changes in spatial-temporal gait variables in this patient population. For example, walking speed, an easily measured gait parameter, predicts disease burden in patients with rheumatoid ankle arthritis[21]. When Khazzam and colleagues[22] analyzed degenerative joint disease involving the ankle, they reported that diseased ankles had decreased range of motion during gait that could be a result of pain, bony deformity, or muscle weakness. They also found that decreased American Orthopaedic Foot and Ankle Society (AOFAS) scores followed decreases in walking speed, cadence, stride length, and ROM.

Table II
Means and standard deviations of functional assessments and gait by tibiotalar alignment

	Valgus		Neutral		Varus		$P=$
	Mean	95% CI	Mean	95% CI	Mean	95% CI	
TUG (s)	9.21	7.9, 10.6	9.94*	8.6, 11.2	8.158*	7.6, 8.8	0.05
FADI score (%)	44.84	39.9, 49.7	46.76	42.9, 50.6	46.59	42.8, 50.3	0.78
Mean walking speed (m/s)	0.86	0.74, 0.99	0.86	0.77, 0.94	0.900	0.82, 0.98	0.75
Mean stance time (s)	0.75	0.69, 0.81	0.72	0.68, 0.76	0.723	0.69, 0.75	0.57
Mean step length (NORM)	0.29	0.26, 0.32	0.29	0.27, 0.32	0.314	0.29, 0.34	0.38
Mean stride length (NORM)	0.583	0.52, 0.64	0.58	0.54, 0.62	0.608	0.56, 0.66	0.69
Mean stride width (NORM)	0.085	0.07, 0.10	0.08	0.08, 0.09	0.084	0.07, 0.09	0.95
Single support (%)	32.77	30.6, 34.9	33.77	31.9, 35.6	33.54	32.5, 34.5	0.63

NORM – data normalized to the gait cycle.
* Group means significantly different from each other.

Similarly, while more restricted ankle joint movement was associated with the arthritic ankle, changes in gait mechanics did not correlate with functional disability[23]. Further, when comparing normal patients to ankle OA patients, the latter group had a significant reduction in AOFAS and Short-Form-36 scores, a deficiency of several gait parameters (cadence, walking speed, stride time, step time, stride length, and step length), and decreased range of motion at the ankle joint[24].

While the aforementioned studies provide information on gait changes unique to patients with an arthritic ankle vs patients with normal ankles, no study to date has focused on whether coronal plane tibiotalar alignment influences spatial-temporal gait variables in the osteoarthritic ankle. Such an assessment would address the role of malalignment in intrinsic losses of function or alteration in spatial-temporal gait variables. Although other studies have certainly focused on clinical assessment of the arthritic ankle, they have not adequately addressed causes or predictive factors of gait changes and functional losses. The data from this study show that Kim's definition of coronal tibiotalar alignment[15] does not discriminate group differences in spatial-temporal gait variables. Only the functional TUG was different between the neutral and varus groups. This result is important considering that most patients with ankle OA exhibit some degree of malalignment.

After failure of conservative interventions, surgical management needs to be considered for end-stage ankle OA. We were unable to find any study that specifically analyzed the difference in pre-operative ankle function or gait mechanics of patients based on coronal plane tibiotalar alignment. Such an assessment is critical not only to address overall post-operative outcome with a particular prosthesis or procedure, as described in the previous studies, but also to determine if post-operative implant failure is more closely related to a particular pre-operative alignment. It may be that a particular coronal plane tibiotalar alignment is more closely associated with osteolysis around the subtalar component or that alignment is better corrected by different ligamentous stabilization techniques. Considering that correction of coronal plane tibiotalar malalignment is one of the major goals of both total ankle replacement (TAR) and arthrodesis, it seems remiss that the literature fails to document correction of pre-operative alignment.

For the purposes of this study, the ipsilateral ankle was not a useful comparison because it is likely that its gait mechanics are also disturbed as a result of compensating for the arthritic ankle. Also, as it pertains to the future study endpoint of following these patients postoperatively and comparing outcomes based on pre-operative coronal plane tibiotalar alignment, function, and gait mechanics, the ipsilateral ankle's mechanics will compensate as a result of surgical correction of the arthritic ankle. Finally, while there are multitudes of other kinetic and kinematic gait variables, our selection of variables is much like those included in other studies.

In conclusion, tibiotalar alignment in the coronal plane (varus, neutral, valgus) had little impact on spatial-temporal gait variables in the ankle of patients with end-stage OA. Our data showed no group differences in ankle mechanics during self-paced walking. Differences in clinical and patient-related assessment of function were limited to a single functional task, the timed up and go test. Future studies should extend these observations by addressing post-operative mechanical and functional outcomes according to surgical procedure and prosthesis.

Author contributions

All authors were involved with the drafting and revising of the manuscript as well as having approved the manuscript for publication.

Robin M. Queen, PhD – the conception and design of the study, and acquisition of data, and analysis and interpretation of data.

Jessica Carter, BS – analysis and interpretation of data.

Samuel B. Adams, Jr., MD – acquisition of data and analysis and interpretation of data.

Mark Easley, MD – the conception and design of the study and analysis and interpretation of data.

James DeOrio, MD – the conception and design of the study and analysis and interpretation of data.

James A. Nunley, MD – the conception and design of the study and analysis and interpretation of data.

Robin M. Queen (robin.queen@duke.edu) and James A Nunley (nunle001@mc.duke.edu) take responsibility for the integrity of this work from inception to the finished manuscript.

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Conflict of interest

None of the authors declare any competing interests in relation to this study.

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